Title: Vacuum Policy for APS Beamlines

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1. Introduction

1.1 Purpose

The lifetime and stability of the electron beam within the APS storage ring requires that the pressure within the storage-ring and the front-end vacuum chambers be maintained as low as possible and that contamination, which would affect the vacuum or jeopardize the effectiveness of the vacuum pumping, be minimized. Because the beamline vacuum can affect, either directly or through an accident, the front-end and storage-ring vacuum and other aspects of the operation of the facility, the APS has established the policy specified in this document for beamline vacuum designs. If the beamline design cannot comply with requirements as stated in this policy, variances will be reviewed and approved on a case-by-case basis upon written request to the APS User Technical Interface.

1.2 Scope

This policy applies to all x-ray beamlines and is to be complied with by beamline designers, builders, and users. This policy states the minimum *requirements* to be met and the *recommendations* to be followed to ensure that beamline vacuum conditions will not affect facility operation. This policy remains in effect and encompasses the facility operating conditions expected through commissioning and beyond. This policy will be modified as operating conditions and/or requirements change.

There are other design requirements that are closely related to the vacuum policy, such as those related to radiation shielding and ozone abatement, and these should be addressed in the development of the beamline vacuum design. This policy is based upon the required vacuum conditions at the front-end to beamline interface and the required vacuum barriers that isolate the beamline from the front end rather than on generalized beamline transport vacuum specifications (i.e., vacuum conditions in each beamline transport segment are not specified).

1.3 Terminology

The terms used in the remainder of this document are defined in the following subsections.

1.3.1 Vacuum Level Specifications

In the following specifications, *beamline* and *beamline section* refer to any portion of a beamline located on the APS Experiment Hall floor, and the interlock level thresholds are the values for design and operation.

Ultra-High Vacuum (UHV)

An ultrahigh vacuum beamline section will have vacuum interlock levels set at $\leq 1 \times 10^{-8}$ torr and will be constructed of UHV-compatible materials. Ultrahigh vacuum sections will be all metal (with the exception of Viton-sealed gate valves) and will have no in-vacuum, liquid-coolant joints within the vacuum envelope.

High Vacuum (HV)

A high vacuum beamline section will have vacuum interlock levels set at $\leq 1 \times 10^{-6}$ torr and will be constructed of HV-compatible materials.
High Vacuum with No In-Vacuum, Liquid-Coolant Joints (HV)*
A HV* beamline section is the special case of an HV section that will have no in-vacuum, coolant (except liquid nitrogen) joints within the vacuum envelope.

Medium Vacuum (MV)

A medium vacuum beamline section will have vacuum interlock levels set at 1×10^{-3} torr.

1.3.2 Front End

The beamline front end provides the UHV transition from the APS storage ring through the ratchet wall to the portions of the beamline located on the APS Experiment Hall floor. Most of the front end is located within the storage-ring shielding tunnel. The front end is terminated by a window assembly or in the case of a differentially pumped front end, by a Beamline Isolation Valve (BIV), located outside the storage-ring shielding tunnel, which provides some degree of vacuum isolation between the beamline and the rest of the front end and the storage ring. The front end is installed and maintained by the APS.

Following installation, the front end will be terminated with a Be window assembly. Once reliable operation has been established, the beamline may request to exchange the Be window termination for a differential pump equipped with a residual gas analyzer head (RGA), or another window suitable for user needs.

1.3.3 Beamline Vacuum Partitions

1.3.3.1 Windows and Barriers

Beryllium Window

In a beamline on the APS Experiment Hall floor, it may be necessary to have sections with different vacuum requirements. Such sections may be terminated by having a beryllium window as the barrier. A beryllium window, for the purpose of this policy, must be made of beryllium that is at least 250 µm thick and must be able to withstand a pressure differential of more than 900 torr.

1.3.3.2 APS Front-End Terminations

1) Bending-Magnet Terminations

For the APS bending-magnet beamlines, the following window design will be used:

> Front-end window assembly, typically with a 8.8 mm x 145 mm aperture, consisting of 2 Be windows, each with a thickness of 250 µm, separated by a vacuum space with independent pumping.

2) Wiggler Terminations

For the APS wiggler beamlines, the following window design will be used:

> Wiggler front-end window assembly, filter protected, typically with a 8.8 mm x 72 mm aperture, consisting of 2 Be windows, each with a thickness of 250 µm, separated by a vacuum space with independent pumping.

3) Undulator Terminations

> a) A front-end, double beryllium window with an integral fixed mask, typically with a 4.5 mm x 4.5 mm aperture and power filters for protection of the window. Each piece of beryllium is 250 µm thick and the space between them is under vacuum maintained with independent pumping.
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> b) A window consisting of an integral mask, typically with a 2x3 mm, or smaller, aperture followed by a single piece of Berylium, 500 µm thick, when approved by the AES Vacuum Technology group.

4) Differential pumps

Differential pumps may be used on the beamlines to separate the front end from the rest of the beamline. Differential pumps are made up of one or more vacuum chambers containing ion pumps and separated by apertures to maintain a pressure at the upstream end of less than or equal to 10^{-9} torr. The beamline must equip the downstream side of the undulator differential pump with an APS-specified residual gas analyzer (beamline RGA) head which will be monitored by the APS. The beamline will also provide a beamline inline gate valve (BIV) to isolate the differential pump. It is preffered that installation and operation of the BIV valve will be the responsibility of ASD. This is not mandatory however. After the beamline personnel have gained some experience operating the beamline successfully with a window, windowless operation using a differential pumping station may be allowed. The beamline personnel can integrate the BIV valve into their beamline operations, or ASD will integrate the BIV valve into the beamline front end operations.

1.3.4 White and Monochromatic Beam

White Beam

An x-ray beam whose spectral characteristics have not been modified from those produced by an insertion device or bending-magnet source, except through the introduction of filters, is referred to as white beam in this document. In addition, for the purpose of this vacuum policy, the term white beam includes beams that have been reflected from a mirror, but are not monochromatic (see next paragraph).

Monochromatic Beam

In this document, a monochromatic beam is an x-ray beam whose spectral characteristics have been defined by a monochromator to select an energy, along with its harmonics, and with a relatively narrow bandwidth, typically much less than a few percent. Again, this definition is used only for the purpose of this vacuum policy.

1.4 Compliance

Beamline designs shall comply with the requirements stated in this policy. It is expected that technical and scientific needs of the beamline might require deviations in the beamline vacuum design from those required by the policy. These special needs should be brought to the attention of the APS as early as possible and also at the time of beamline design reviews. After a risk analysis is performed, the beamline will work with the APS towards an appropriate solution.
The beamline management will ensure that beamline members and independent investigators comply with the vacuum policy during beamline operations.

2. Beamline Vacuum Design

To ensure the protection of the APS storage ring and the beamline front ends, the APS requires that the following simple rules be followed.

2.1 General Rules for Beamline Vacuum Design

- Vacuum is required on the beamline side of the APS front-end/beamline interface.
  - If the front end is equipped with a standard beryllium window (2 x 250 µm or 1 x 500 µm), then a minimum of medium vacuum (MV) is required on the beamline side of the window.
  - If the front end is equipped with a differential pump, then 1) UHV or HV* is required on the beamline side of the differential pump, 2) the differential pump is isolated from the beamline by a beamline supplied gate valve (BIV), and 3) the beamline vacuum will be monitored by the APS using a UHV nude ion gauge and the RGA.
- For beamlines in which the white beam will be propagated in atmosphere, a minimum of two beryllium windows are required to isolate the front end from atmosphere. Each window must be at least 250 microns thick.
- For beamlines in which white beam is to be brought out of the beamline vacuum, the downstream beryllium window must be protected from oxidation with an additional window (for example Diamond, Kapton, Aluminum, etc)
- At least one beryllium window, with a minimum thickness of 250 microns, is required to isolate beamline sections with medium vacuum or with in-vacuum, liquid-coolant joint.

2.2 Operation of APS Beamlines Using a Window

In general, beamline windows provide additional integrity in the vacuum design of the beamline, may ease the constraints of vacuum design, and simplify some beamline operations. Where consistent with the scientific objectives of the beamline, especially at higher energies where the reduction in flux through the window will be less, the APS encourages the use of windows to enhance the protection of the front end and storage ring, as well as beamline components.

2.3 Windowless Operation

Normally, windowless operation will only be permitted after a beamline has been operated successfully with a window. If the beamline is permitted to operate without a window, the existing window will be replaced by a standard differential pump. The section of beamline downstream of the differential pump and upstream of a window must be either UHV or HV* and be free of quick-couple style flanges. The APS will use the front-end RGA and a beamline supplied beamline RGA and nude ion gauge to

monitor the vacuum conditions at the differential pump to beamline interface and in the front end. The beamline RGA spectrum must be equal to UHV or HV* defined pressure, or better, and be consistent with a contamination free vacuum in order to open the beamline supplied BIV valve.
In windowless operation, the RGA spectrum must be consistent with a contamination-free vacuum. Specifically, the residual gases should be hydrogen (M=2), methane (M=12 to 16), water (M=16 to 18), nitrogen (M=14, and 28), carbon monoxide (M=28) and carbon dioxide (M=44). In unbaked systems, the predominate peaks will be at M=2, 18, and 28. In baked systems, the predominate peaks will be at M=2, 16, 18, 28, and 44. If the RGA spectrum includes M=40 (argon) or M=32 (oxygen), this indicates that the system probably has a leak. Because the halides, chlorine and fluorine (M=19, 35, or 37), will poison NEG pumping strips, the windowless beamline spectrum must be free of these gases prior to opening the front-end exit valve. If the spectrum includes peaks at M=39, 41, 55, and 57, the beamline is probably contaminated by organic material and a peak at M=36 indicates that hydrogen sulfide is present. For windowless operation, the front-end exit valve will be opened only after the RGA test described in Section 6 has been passed.

3. Interlocks and Equipment Protection Systems

The front end contains a storage-ring isolation valve, a slow vacuum valve, a fast vacuum valve, a pair of pneumatically actuated photon shutters, two bremstrahlung shields and several aperture defining masks, and the front-end exit valve. In addition there is a Beamline Isolation Valve (BIV) for beamlines with differential pumps rather than windows as the front end to beamline transition. The APS has designed an equipment protection system (EPS) for the front end, which interfaces with the storage-ring equipment protection system. The APS will specify which interlocks are required as part of the beamline EPS system.

A fast-valve sensor is located directly downstream of the shield wall and is provided to protect the storage ring and the front end in the event of a catastrophic beamline vacuum failure and *vice versa*. In case of an accidental break in the beamline vacuum system resulting in a fast-valve trip, the front-end shutters, the slow valve, and the front-end exit valve will close as will the fast valve. In all cases a fast valve trip will dump the stored beam in the ring.

If a slow pressure increase is detected in the front end, resulting from a slow leak or pump failure, the front-end shutters, the slow valve, and the front-end exit valve will close and seal. PS1 will close to protect the slow valve.

Only an authorized APS staff member can open any of the front-end valves. The APS will define the specific procedure that must be followed to return the beamline to operation.

The APS recommends a beamline protection system to monitor vacuum conditions of the beamline. In order to reduce spurious vacuum trips of the beamline, or the front-ends, polling logic on the ion pump set points is recommended.

Note that the vacuum conditions in beam transports must be consistent with their shielding. The shielding specifications for transport provided in ANL/APS/TB-7 Section 4.3 are for evacuated transport. Other non-evacuated conditions, such as He-filled transport, are considered special cases and must be addressed on a case-by-case basis. The user should refer to TB-7 for additional guidance.

4. Beamline Vacuum Equipment

4.1 Vacuum Pumps

Because of concerns about noise and vibration on the APS Experiment Hall floor, it is preferred that ion pumps be used on beamline transports.

Sputter-ion pumps, titanium sublimation pumps, cryo-pumps, "oil-free" turbomolecular pumps, and NEG pumps are permitted as primary pumps in the UHV and HV* sections of beamlines. The cryo- and turbo-pumps must be equipped with appropriately interlocked isolation valves for beamline protection in case of a pressure and/or power failure.

During bakeout or rough pumping of the beamline or at the experiment stations, properly backed turbo-pumps, sorption pumps, or any other pumps approved by the APS may be used. When these pumps are used at an experiment station or a first optics enclosure, they must be equipped with appropriate interlocks and isolation valves to protect the vacuum system in case of a pressure rise and/or power failure. Because of potential beamline vacuum contamination and pump exhaust problems, it is required that oil-free mechanical pumps be used as backing or roughing pumps on all sections of beamlines and experimental equipment.

Diffusion pumps are not permitted for beamline pumping.

4.2 Gauges

For safety reasons, glass ionization gauges are *not permitted* in any sections of APS beamlines. Nude ionization gauges or cold cathode gauges are recommended. Penning gauges are particularly attractive because of their wide range (from 10^{-3} to 10^{-11} torr). When cold cathode or ionization gauges are operated, the vacuum chamber must be electrically grounded to the ion-gauge controller ground. Proper grounding is mandatory to eliminate the potential of high voltages on vacuum-system components. The collector cable must be safely shielded. The beamline personnel will be responsible for ensuring and demonstrating to the APS that the components are properly grounded and shielded.

5. Vacuum Design Approval

Beamline personnel will be responsible for the vacuum design and will ensure that the quality of the storage-ring vacuum is not degraded during the beamline operation. The latter can be achieved by following the APS beamline vacuum policy stated in this document. Beamlines are required to submit vacuum-design-related information as a part of the material for the beamline design reviews. Planned in-vacuum, liquid-coolant joints should be identified in the beamline design reports. It is also required that the beamlines meet the performance tests outlined in Section 6 for integrating the beamline vacuum with that of the front end.

6. Requirements for Integrating the Beamline and Front-End Vacuum

After any part of the beamline is brought up to air (or preferably to dry nitrogen) at ambient pressure or after its closure due to the detection of a vacuum fault, the following conditions must be satisfied before the front-end exit valve is opened:

1. The pressure at the front-end/beamline interface must be less than or equal to:
   - 10^{-3} torr if the front end is terminated with a double beryllium window, or
   - 10^{-6} torr if the front end is terminated with a differential pump with a monitored RGA, without in-vacuum, liquid-coolant joints within the vacuum envelope.

2. In windowless operation, the residual gas spectral analysis is performed using the RGA located on the downstream end of the differential pump. The residual gas spectrum must be consistent with a contamination-free vacuum. It must indicate that the sum of the M >= 46 components is $\leq 1 \times 10^{-9}$ torr. It must also show that the partial pressure of each component with masses corresponding to M equal to 19, 35, 37, 39, 41, 55, and 57 must be $\leq 5\times10^{-11}$ torr.

3. Prior to startup of a beamline configured with or without a window or a new experiment in which the experimental sample shares the beamline vacuum, the user must demonstrate to the APS Floor Coordinator that all the vacuum interlocks in the UHV and HV* parts of the beamlines and equipment chambers are operational, that pumps are properly vented and equipped with appropriate isolation valves to protect the vacuum in case of overpressure and/or power failures, and that adequate measures have

been provided to protect the front-end and storage-ring vacuum from an accidental break in the vacuum system of the beamline on the Experiment Hall floor.

If the beamline is to be vented so as to no longer meet the vacuum requirements at the front termination, then the front-end slow valve and the front-end exit valve must be closed. On differential pump terminated beamlines, the valve between the beamline and the differential pump shall be closed prior to venting the beamline and shall remain closed until a RGA scan has shown the beamline vacuum to be contamination free.

7. Vacuum Policy Summary

FE to Beamline Transition

Transition Barrier	Vacuum requirement	
Differential Pump	UHV or HV*	RGA and Gate Valve Required
Be Window	UHV, HV*, HV or MV	

Other Considerations

Vacuum transition	A single Be Window
Mono beam transition to atmosphere	A minimum of 2 windows. UHV or HV* beamlines with a differential pump may have a single window to atmosphere
White beam transition to atmosphere	A minimum of 2 windows. The final Be window must have oxidation prevention. For example a downstream Diamond, Kapton or Aluminum window with the intervening volume either pumped or flushed with Helium
Beamline venting	At least one enclosed buffer zone, requiring 2 downstream valves to be closed

Notes
Beryllium window thickness must be 250 μm or greater
Any exceptions to the vacuum policy will be handled on a case-by-case basis by the APS User Technical Interface.

Definition of vacuum requirements

Ultra-High Vacuum (UHV)

An ultrahigh vacuum beamline section will have vacuum interlock levels set at $\leq 1 \times 10^{-8}$ torr and will be constructed of UHV-compatible materials. Ultrahigh vacuum sections will be all metal (with the exception of Viton-sealed gate valves) and will have no in-vacuum, liquid-coolant joints within the vacuum envelope.

High Vacuum (HV)

A high vacuum beamline section will have vacuum interlock levels set at $\leq 1 \times 10^{-6}$ torr and will be constructed of HV-compatible materials.

High Vacuum with No In-Vacuum, Liquid-Coolant Joints (HV)*

A HV* beamline section is the special case of an HV section that will have no in-vacuum, coolant (except liquid nitrogen) joints within the vacuum envelope.

Medium Vacuum (MV)

A medium vacuum beamline section will have vacuum interlock levels set at 1×10^{-3} torr.

8. References

The following references may be consulted for additional details concerning acceptable vacuum practices:

1. *Vacuum Technology*, by A. Roth, Elsevier Sciences Publishers, 1990 (3rd Edition).

2. *High-Vacuum Technology*, by Marsbed H. Hablanian, Marcel Dekker, Inc., 1990.

3. *Theory and Practice of Vacuum Technology*, by Max Wutz, Hermann Adam and Wilhelm Walcher, Friedr. Vieweg & Sohn, 1989.

4. *Advanced Photon Source Accelerator Ultrahigh Vacuum Guide*, by C. Liu and J. Noonan, ANL/APS/TB-16, 1994.